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Ecological Footprint in relation to Climate Change Strategy in Cities

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Abstract. Ecological footprint determines how much natural resources are consumed by an individual, city, region, state or all inhabitants of our planet in order to ensure their requirements and needs. It includes all activities, from food consumption, housing, transport to waste produced and allows us to compare particular activities and their impacts on the environment and natural resources. Ecological footprint is important issue for making sustainable development concept more popular using simplifications, which provide the public with basic information on situation on our planet. Today we know calculations of global (worldwide), national and local ecological footprints. During our research in cities, we were concentrated on calculation of city's ecological footprint. The article tries to outline theoretical and assumptions and practical results of climate change consequences in cities of Bratislava and Nitra (Slovakia), to describe potential of mitigating adverse impacts of climate change and to provide information for general and professional public on theoretical assumptions in calculating ecological footprint. The intention is to present innovation of ecological footprint calculation, taking into consideration ecological stability of a city (with a specific focus on micro-climate functions of green areas). Present possibilities to reduce ecological footprint are presented.

1. Introduction

Sustainable development of a city is conditioned by several factors related to human settlements with its activities. The connection between those settlements and philosophy of sustainability is evident in many decision-making problems of urban areas and, at the same time, urban problems caused by cities themselves. In many cases the urbanization processes have caused the rapid increase of paved surfaces and the rapid decrease of green areas. This situation resulted in a city climate change associated with the deterioration of human's environment, soil, and water and air pollution.

During a second half of 20th century we can see that urban settlements has become an issue in the research field. The reason for that is that people recognized a question of urban space quality being the result of a comprehensive set of impacts.

Today we all realise that our planet's resources are limited. In the recent decade the ratio between available resources and their global consumption began to be expressed in a so called ecological footprint. Ecological footprint determines how much natural resources is consumed by an individual, city, region, state or all inhabitants of our planet in order to ensure their requirements and needs. It includes all activities, from food consumption, housing, transport to waste produced and allows us to compare particular activities and their impacts on the environment and natural resources. Ecological footprint is important for making sustainable development issue more popular, using simplifications which provide the public with basic information on situation on our planet, [1, 2].



During our research in cities we were concentrated on theoretical assumptions and practical results of climate change consequences in cities of Bratislava and Nitra (Slovakia), to describe potential of mitigating adverse impacts of climate change. Our research was aimed at evaluation of microclimatic factors, quality of air and water and selected physical and chemical characteristics of soil. Furthermore, the influence of potential environmental aspects on human health on selected areas with different proportion of vegetation and paved surface was observed stressing the relationship between the observed parameters and urban area. Areas with high proportion of paved surfaces and high density of architectural elements with lack of vegetation in average has the highest values of air temperature, remarkably lower air humidity and the quality of air in average is worse in comparison to areas with higher proportion of vegetation. Lower proportion of vegetation and minor density of built-up areas was increasing the air circulation that remarkably influenced the temperature and the quality of air. Besides the shading of vegetation, there is another factor that influences the surface temperature – water supply. On the basis of research of thermo-physical conditions of the soil influenced by its changing humidity we can say that thermal conductivity is decreasing with increasing temperature. Surface temperature of soil is dependent on thermal capacity of the soil that is influenced by the amount of water in soil and its evaporation and thermal conductivity.

Microclimatic conditions of urbanized area of Bratislava and Nitra were evidently affected by vegetation due to evapotranspiration or the provided shade. Microclimate of the urbanized area of both cities were affected by the adequate proportion of the paved areas and areas with vegetation as well as by the quality of vegetation and its maintenance.

During our research in cities we were concentrated on calculation of city's ecological footprint in relation to potential mitigation of adverse impacts of climate change. In the light of our research with a specific focus on micro-climate functions of green areas we decided to innovate the ecological footprint calculation, taking into consideration ecological stability of a city. Present possibilities to reduce ecological footprint are also presented.

2. Methodology of ecological footprint calculation

Ecological footprint is measured in so called global hectares (gha). Global hectare is 1 hectare of biologically productive space with average world productivity. In 2001, the biosphere had 11.2 billion hectares of biologically active areas which corresponded approximately to one fourth of the planet's surface. This area of 11.2 billion hectares covers 2.3 billion hectares of waters (ocean shelves and inland waters) and 9 billion hectares of dry land. The dry land consists of 1.5 billion hectares of crop land, 3.5 billion hectares of pastures, 3.9 billion hectares of forests and 0.2 billion hectares of built-up areas.

Bio-productivity (biological productivity) is identical with biological productivity per hectare and per year. Biological productivity is normally measured as accumulation of biomass per year. Biocapacity is usable capacity of biological production during given year on a biologically productive area, expressed also in global hectares. Based on known and available data, ecological footprint and biocapacity can be calculated for an individual, municipality, state, etc. The WWF publishes annually a report on ecological footprint of world states. On the basis of this report, total ecological footprint of our planet is 2.2 gha, while biocapacity is only 1.8 gha.

Recalculation of various land and sea types ha/gha uses so called equivalence factors which express relative (world, i.e. global) bioproductivity. Yields factors are used to make a more precise specification at country level, determining bioproductivity of particular countries. The so called equivalence factors constitutes the amount of global hectares contained in an average hectare of crop land, built-up territory, forests, pastures or fisheries area. Equivalence factors are derived from sustainability index and expressed according to so called global agro-ecological zones. Equivalence factors describe potential yield which can be achieved under expected use of irrigation, fertilisers, etc.

In accordance with the above-mentioned each inhabitant of our planet should use not more than 1.8 global hectares in order to assure environmental sustainability. In practice it means a substantial reduction of resource consumption on one hand (developed countries of the North) and increasing use

of the Earth's biocapacity on other hand (developing countries). A number of highly developed countries with a high level of welfare measured as human development index have relatively low ecological footprint. Human development index includes average life expectancy, education level and gross domestic product per capita.

If we would like to evaluate countries oriented really towards sustainable development, such countries would be located on an intersection point of two axes: axe of the planet's biocapacity available and axe of HDI index equal to 0.8 or higher.

Ecological footprint and biocapacity are used to clearly and understandably demonstrate:

- extent of requirements of human population to ensure its existence under current needs and technology,
- whether average consumption per capita is sustainable and fair in comparison to the global, worldwide consumption and biocapacity available.

Today we know calculations of global (worldwide), national and local ecological footprints. Currently, there are several ways in calculation of ecological footprint, though the calculation methodology is still improving. The Redefining Progress organisation belongs to the pioneers in this area. This organisation has created a methodology for calculation of a city's ecological footprint on the basis of determining the amount of renewable and non-renewable ecologically productive area which is required to ensure all resources for urban inhabitants and to absorb wastes.

Ecological footprint calculation includes, for example, current consumption and availability of resources, however without negative impact on the environment (e.g. destruction of ecosystems, deforestation, acid rain effects) which will be manifested in the future in the form of biocapacity reduction. Similarly, other sustainability areas are ignored too, such as social and environmental areas.

Built-up areas are perceived with a certain hesitation in calculations. Areas needed for housing infrastructure, transport, industrial production and hydropower plants cover a substantial part of the world bioproductivity. Based on the WWF report, assessing the global ecological footprint, this area is the least documented as the satellite pictures with low resolution are not able to reproduce dispersed infrastructure and roads, [3, 5]. The best estimates say that from global point of view the built-up areas cover 0.2 billion hectares. Since from historical point of view cities were localised in fertile agricultural areas with suitable climate and access to fresh water, calculations are determined by an assumption that the built-up areas cover medium cultivated areas. It is assumed that the built-up areas have replaced the crop lands since human settlements are usually situated in the most fertile landscape areas. In 2001, the footprint of built-up areas was 0.44 billion global hectares, but preciseness of this calculation is limited by the above mentioned uncertainties in background data.

Moreover, a number of elements can be distinguished within the built-up territory of a city: really built-up areas (areas covered by impermeable surface, such as roads, buildings, parking areas, trade and industrial premises), but also various types of anthropogenic and natural biotopes. Green areas play important role not only from the point of view of city climate with considerable climate change consequences but for assessing the stability of urban environment as well.

Ecological stability indirectly affects also other components of ecological footprint. Suburbanisation with growth of transport needs (moving to suburbs due to inappropriate environment in city centres leads to excessive urban growth and increasing transport demands), growth of energy consumption, etc. Defining the term of ecological stability and its evaluation is relatively complicated methodological process. With a certain simplification we can say that ecological stability of urban territory is increasing with growing green areas in a city. When calculating ecological footprint this partial indicator is not taken into account. This situation is caused also by the fact that it is impossible to distinguish various types of surfaces by satellite pictures (e.g. in urban areas gardens are not distinguished from paved surfaces, cultural vegetation from large parking area at shopping centre, etc.).

3. Results

3.1. Proposal of innovative ecological footprint calculation (with the application of micro-climate function)

If we perceive ecological footprint as numeral expression of human impacts on landscape, we can assume that there is direct relationship between the value of ecological footprint, level of ecological stability of landscape and level of impact caused by human activities.

Intensive use of territory is accompanied by changes in landscape structure characteristic in particular by loss of natural and semi natural components (forests, meadows, gardens) and also by simultaneous growth of negative impacts, such as water and air pollution, etc. Globally we speak of climate change, at the level of urban agglomerations we speak of urban heat island.

Green areas play irreplaceable role in alleviating heat island effects and climate change. Research results in the area of impact of green areas on the urban microclimate are clear (.....). Based on these results, we can assume that the most efficient components are forests and large trees and the least efficient components in mitigating climate change are grass areas. This led to *an idea to take into account the level of ecological stability of territory when calculating ecological footprint*. The stability is growing with increasing share of natural components. It also reflects the size and number of surfaces which are active in mitigating climate extremes. This active impact on micro-climate will be expressed by so called micro-climate function coefficient and will serve to express ecological footprint in taking account of the share of microclimate functions of vegetation in territory.

In the light with the above mentioned, currently known methodologies of footprint calculation at local/urban level do not include quality of the urban environment, which can be expressed also with the help of sufficient size of green areas, as one of basic indicators of ecological stability of territory. Therefore, we are proposing that the known calculation procedures, based on resource consumption in the areas of shelter, transport, food, goods and services take into account micro-climate function of ecological stability of city's territory.

Micro-climate function coefficient (KMF) will be denominator in the innovative ecological footprint calculation. That means that the higher micro-climate function coefficient (e.g. high share of forests in territory), the lower ecological footprint value:

$$EF = (EF_{\text{food}} + EF_{\text{shelter}} + EF_{\text{transport}} + EF_{\text{goods}}) / K_{mf} \quad (1)$$

The coefficient will be in the range of values of 0.8 – 1.2 which are set so that micro-climate function is not overestimated.

Micro-climate function coefficient for a given territory will be calculated based on formula:

, where: K_{mf} – micro-climate function coefficient of territorial units

p – area of a given / model territory

p_i – area of territorial units determined based on cover rate by wood vegetation

kmf_i – micro-climate function coefficient of territorial units of a given territory

n – number of territorial units in a given territory.

Tables 1 and 2 present examples of innovative assesment of ecological footprint for two types of territory: with high and with low share of microclimatically active surfaces. Under innovative calculation of ecological footprint it is necessary to consider the city boundaries as this will have a substantial impact on calculation itself. It has been proposed to calculate the micro-climate function of a city based on the zoning of territory. That means that calculation of K_{mf} would alternatively take into account:

- Administrative boundaries / cadastre
- Logical natural territory, e.g. 5 km around the built-up area.

Step 1: Getting input data – Elaborating a map according to territorial units of the current landscape structure.

In order to get needed input data for calculation it is possible to use a map of current landscape structure with resolution of landscape components or with vectorisation of purchased orthophotomap. Particular components of landscape structure are identified. A simplified procedure allows us to gain data from culture records at the Cadastre Office and a detailed structure of built-up territory from records of the City Council, from spatial planning documentation, etc.

Step 2: Mapping territorial units, creation of geodatabase

Proposal of territorial units on the basis of percentage of cover by microclimatically active surfaces (cover by wood vegetation) in the urbanised landscape (model territory of Bratislava – Karlova Ves) is presented in table 10. Based on terrain investigation, the individual territorial units are mapped and data are recorded in a created geodatabase according to following criteria:

- Type of territorial unit
- Localisation of territorial unit
- Share of roads, built-up areas, artificial impermeable surfaces in %
- (additional)
- Ratio of grass areas to wood vegetation areas in % (additional):
- Total cover by micro-climatically active surfaces in %:

Step 3: Calculation of Kmf

It is possible to start calculation of the coefficient of micro-climate function of ecological stability according to the methodology based on assigning particular territorial unit coefficients of interest territory and subsequently to calculate the coefficient of territory micro-climate function.

Step 4: New calculation of ecological footprint with inclusion of the new indicator

In accordance with Chapter 6.2 it is relatively simple to calculate the new indicator of ecological footprint with inclusion of the ecological stability in the total calculation footprint:

$$EF = (EF_{\text{food}} + EF_{\text{shelter}} + EF_{\text{transport}} + EF_{\text{goods}}) / KMF \quad (2)$$

3.2. Ecological footprint reduction – a contribution to climate change mitigation

Transport, energy consumption, housing, goods and services, nutrition and others represent areas where negative environmental impacts has been confirmed. In order to reduce or mitigate the consequences of climate change in cities, several proposals in these fields are proposed (see Table 1 and Table 2).

On the other hand, increasing share of vegetation, planting trees, using water components in cities, afforestation and increasing retention capacity of a territory can contribute to climate change mitigation to a high degree, [4, 6, 7].

Table 1. Sectors of energy consumption and emission

A. Transport

Transport is responsible for one third of total energy consumption. As to the CO₂ emissions, this sector represents almost 25 % of the world emissions. Transport has also considerable impacts on the environment and health. Energy intensity of the transport sector is very high, which means that it is also a big producer of greenhouse gas emissions.

B. Energy, housing, goods and services, nutrition

Energy is the most important sector influencing greenhouse gas emissions. This is why it being necessary to concentrate not only on renewable energy resources but on energy saving as well. As regards housing, this concerns in particular heating, water heating and air-conditioning.

C. Increasing share of vegetation, planting trees and using water components in cities, afforestation and increasing retention capacity of a territory

Forest absorbs 500 to 1000 tonnes of carbon on one square km per year. Deforestation itself releases a lot of carbon into the atmosphere where it reacts with oxygen producing carbon dioxide and other two important greenhouse gases – methane and nitrous oxide, [3]. Vegetation in cities plays an important role which indirectly affects also growth of CO₂ emissions, e.g. cooling the space (reducing necessity to use air conditioning), substantial impact on the quality of environment (moving to suburbs due to inappropriate conditions in city centres with city growth and excessive demands for transportation), etc.

Table 2: Examples of proposals to reduce ecological footprint in selected areas

A. Transport

- To work out Sustainable Transport Plans in cities;
- To effectively transport goods (transport on railway and water transport produce less CO₂ than road transport)
- To apply principles of sustainable urbanism and polycentric development in cities, e.g. to support mixed functions of territory (creating new, primarily residential, areas bring large demands for transport);
- To support public transportation means and their upgrade;
- To support alternative (cycling, pedestrian) transport,
- Technical improvements in construction of cars shift to renewable sources (electric vehicles, fuel cells, and hydrogen driven cars), using cars with lower fuel consumption, higher taxes in transport, reducing maximal allowed speed, controlling technical state of cars.
- To use trains for longer distances (railway transport produces 30 times less CO₂ emissions per person than road transport by car);
- To use cars more effectively (more passengers), to drive by reasonable speed, to limit the use of air-condition in car, controlling technical state of cars;
- To use cycling or pedestrian transport for shorter distances;
- Teleconferences and homework (if possible) can also contribute to reduction of transport volume;
- When buying products, it is necessary to prefer products of local production, which supports local producers and reduces transport of goods (especially foods).

B. Energy, housing, goods and services, nutrition

- To replace the current ineffective system of natural resource use based on fossil fuel combustion with cleaner renewable resources (biomass, solar, wind or water energy);
- Economy based on energy efficient technologies can also considerably reduce consumption of fossil fuels (Combined production of electricity and heat is an alternative to traditional electricity production and production of heat for long-distance heating systems. Energy transformation efficiency is here as much as 90 %).
- To support energy passive and low energy houses and buildings.
- Energy efficiency of most of currently used electric appliances is very low – new technologies and appliances, such as energy efficient bulbs (80 % efficiency) can dramatically reduce energy consumption;
- To save energy and water (water treatment plants also consume energy) in households – switching off the light, tap insulation, preferring shower against bathing, switching off appliances and control lights;
- To prefer purchase of energy efficient appliances;
- To use solar panels (e.g. for water heating) and other renewable energy resources;
- To use heat insulation of houses and not to overheat rooms;
- To buy local products and take into account the packaging (recyclable package of product);

- To prefer healthy food cultivated in the organic agriculture (without use of harmful substances);
- To separate and recycle waste (reducing methane production at landfills).

C. Increasing share of vegetation, planting trees and using water components in cities, afforestation and increasing retention capacity of a territory

- Planting trees and adequate tree management in cities;
- Increasing share of vegetation (planting trees in rows, on parking places, between road lanes, alternative use of vegetation – e.g. on roofs where vegetation slow down water run-off, climbing plants, etc.)
- Afforestation, protection of nature and nature components in urban areas;
- Increasing retention capacity of a territory (retaining rainfall water, collection systems, reservoirs, wetland protection and integrated water treatment).

Our intention was to present innovation of ecological footprint calculation, taking into consideration ecological stability of a city (with a specific focus on micro-climate functions of green areas). Finally, it has been decided to present possibilities to reduce ecological footprint and simultaneously to contribute to mitigating the climate change threats.

The premise that adequate proportion of paved surface and surface covered by vegetation can improve the quality of urbanized environment was approved. Areas with high proportion of paved surface and high density of architectural elements with lack of vegetation in average has the highest values of air temperature, lower air humidity and the quality of air in average is worse in comparison to areas with higher proportion of vegetation. Lower proportion of vegetation and minor density of built up area of observed areas was increasing the air circulation that remarkably influenced the temperature and the quality of air. During the warmer months (June, July, August) the lowest air circulation was recorded on most of the observed areas. On the selected areas surface temperature of different surfaces was observed, meanwhile the outstanding.

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